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WISE Photometry (WPHOT)

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Overview

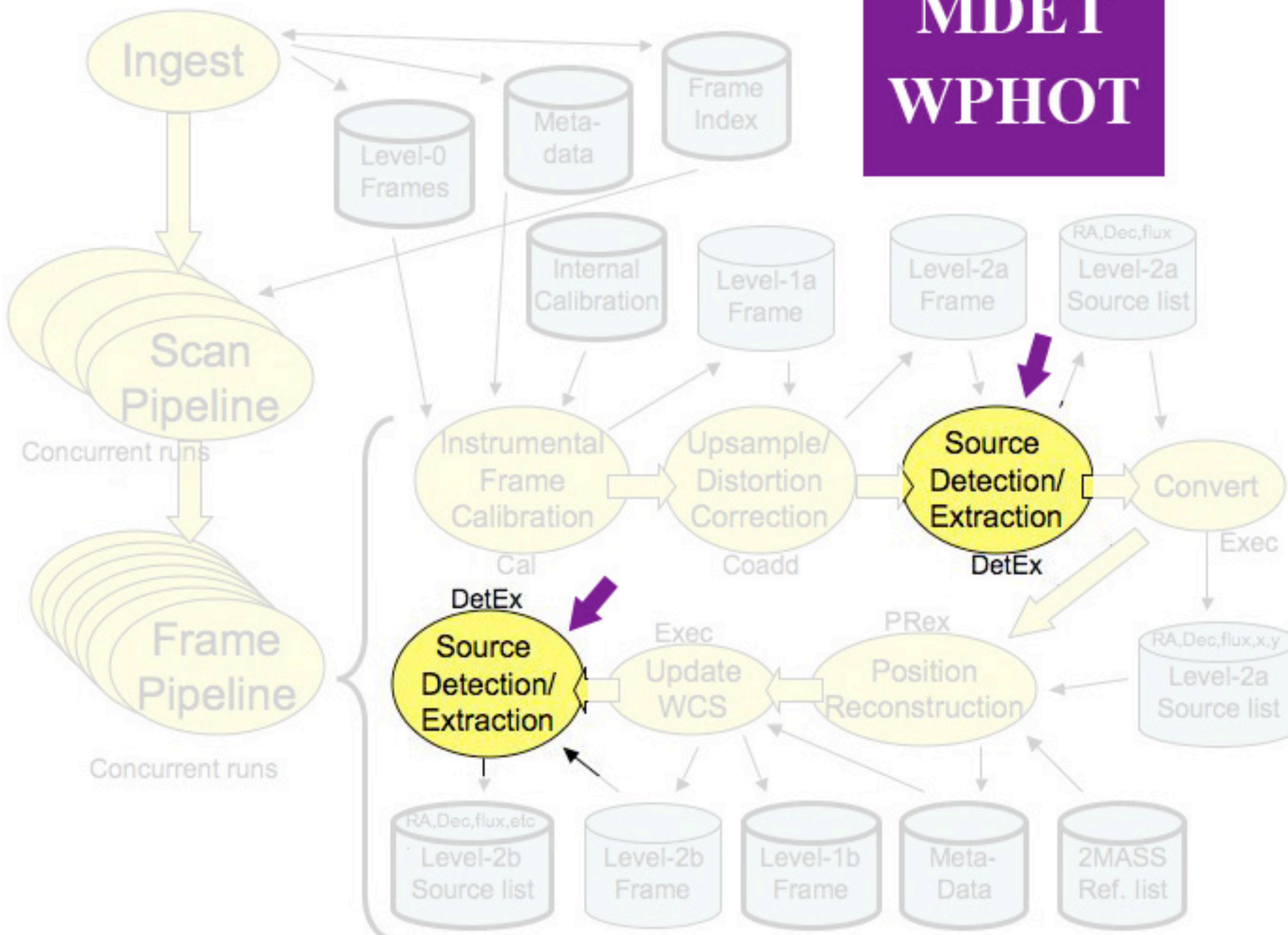
WPHOT is designed to perform the source characterization (source position & fluxes) associated with each of the three stages of source extraction during pipeline processing.

The characterization is based on an input list of source candidate positions produced by MDET using a detection algorithm which makes use of the data at all bands simultaneously.

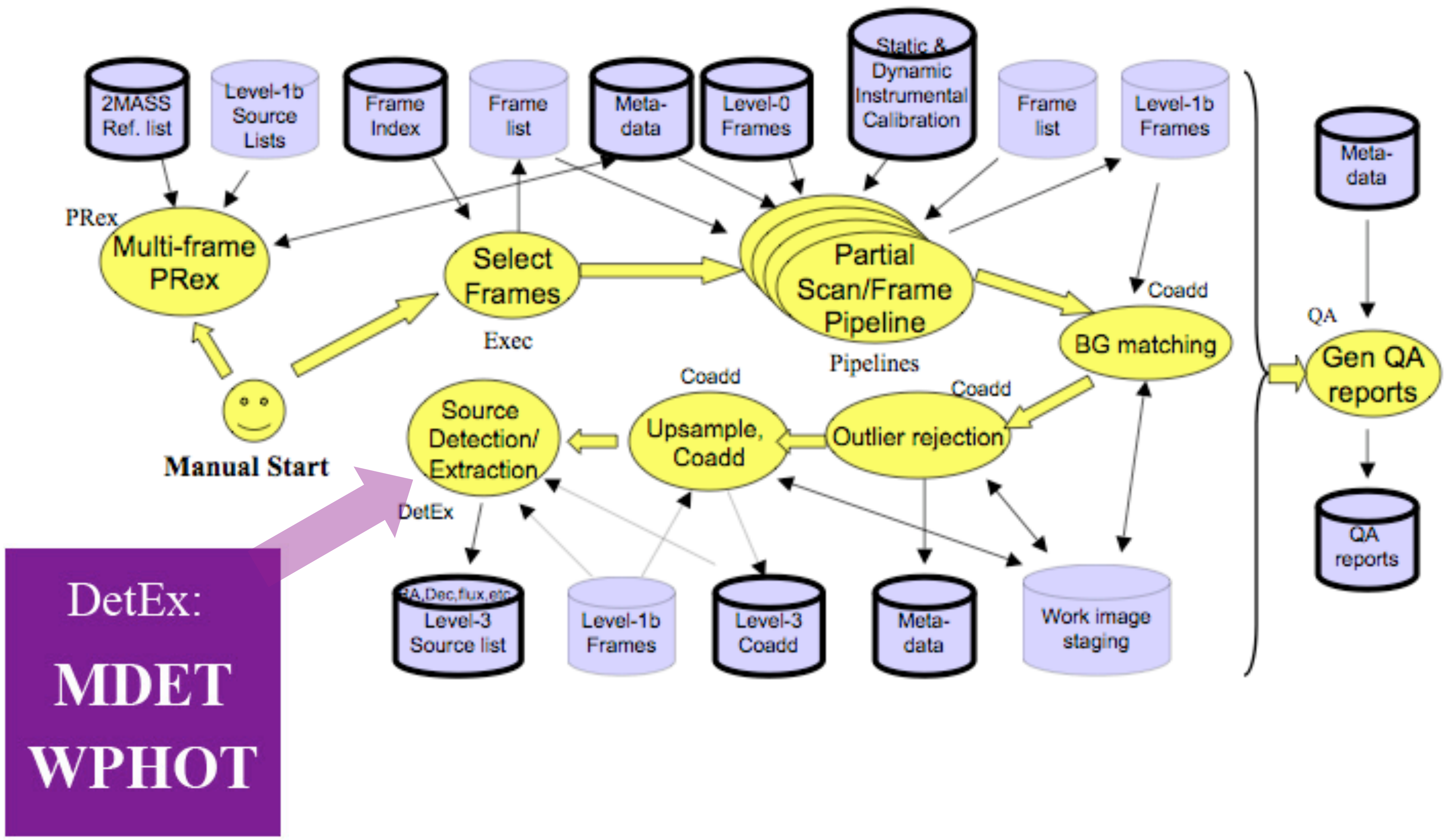
- Profile-fitting (WPRO)
- Aperture Photometry & Characterization (WAPP)

WSDS Scan/Frame Pipeline

DetEx:
MDET
WPHOT



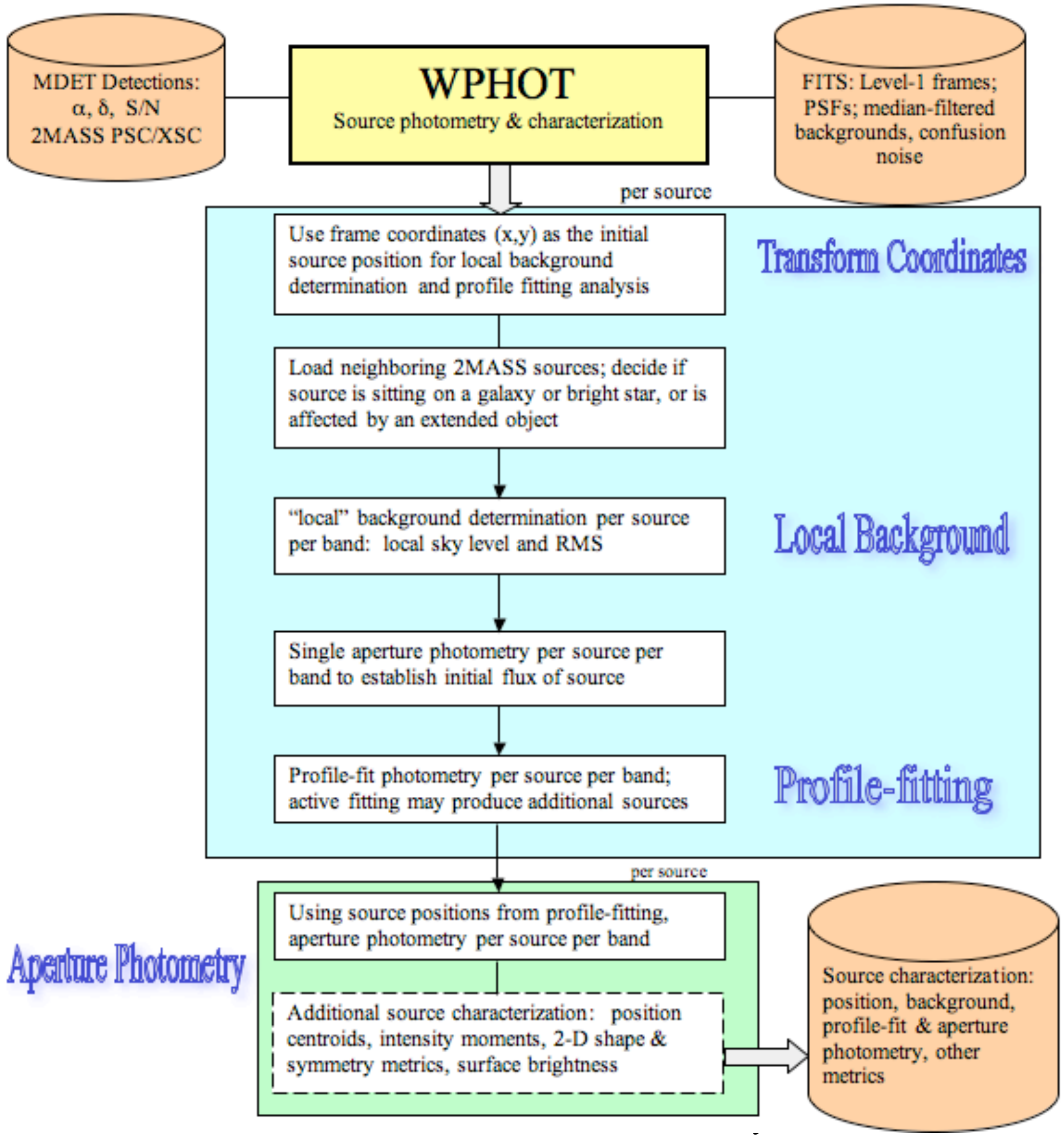
Multi-frame Pipeline



Driving Requirements

- [L4WSDC-002] The WSDC shall produce a Source Catalog derived from the images used to generate the WISE digital Image Atlas.
- [L4WSDC-080] The final WISE Source Catalog shall have greater than 99.9% reliability for sources detected in at least one band with SNR > 20, where the noise includes flux errors due to zodiacal foreground emission, instrumental effects, source photon statistics, and neighboring sources. This requirement shall not apply to sources that are superimposed on an identified artifact. [eliminate?]
- [L4WSDC-009] The final WISE Source Catalog shall be at least 95% complete for sources detected with SNR>20 in at least one band, where the noise includes flux errors due to zodiacal foreground emission, instrumental effects, source photon statistics, and neighboring sources. This requirement shall not apply to sources that are superimposed on an identified artifact.
- [L4WSDC-010] The final WISE Source Catalog shall include sources down to SNR=5 in any band, and the completeness and reliability of sources in the Catalog shall be characterized at all flux levels.
- [L4WSDC-012] Flux measurements in the WISE Source Catalog shall have a SNR of five or more for point sources with fluxes of 0.12, 0.16, 0.65 and 2.6 mJy at 3.3, 4.7, 12 and 23 μm, respectively, assuming 8 independent exposures and where the noise flux errors due to zodiacal foreground emission, instrumental effects, source photon statistics, and neighboring sources.
- [L4WSDC-013] The root mean square error in relative photometric accuracy in the WISE Source Catalog shall be better than 7% in each band for unsaturated point sources with SNR>100, where the noise flux errors due to zodiacal foreground emission, instrumental effects source photon statistics, and neighboring sources. This requirement shall not apply to sources that superimposed on an identified artifact.
- [L4WSDC-015] The WISE Source Catalog shall contain the measured in-band fluxes or flux upper-limits in the four WISE bands for objects detected in at least one band in the WISE Atlas Images.
- [L4WSDC-016] The WISE Source Catalog shall contain uncertainties in the flux measurements (one sigma) in all bands for which a source is detected.
- [L4WSDC-018] The WISE Source Catalog shall contain uncertainties in the coordinates measurements for each object.
- [L4WSDC-043] The WSDS Pipeline processing shall detect sources down to a threshold of at least five times the image noise from the calibrated image frames, and the combined Atlas Images.
- [L4WSDC-044] The WSDS Pipeline processing shall merge source detections in the four WISE bands into a single source catalog entry.
- [L4WSDC-049] The WSDS Pipeline shall be robust to data missing from one or more bands.

WPHOT Processing Flow



Profile-Fitting Photometry (WPRO)

- Based on maximum likelihood fit of PSFs to pixel values at all bands simultaneously
- Multiband descendent of PROPHOT (2MASS)
- Advantages of multiband fit:
  1. High resolution data at short wavelengths can guide the fitting procedure at the longer wavelengths where the resolution is poorer
  2. No post-extraction bandmerge step is required, thus avoiding cross-band matching ambiguities in crowded fields
  3. Optimal band-filling (valid measurement in band(s) that may not otherwise be detected)

Models for maximum likelihood estimation

Measurement model:

$$\rho_{\lambda i} = \sum_{n=1}^{N_{\rm B}} (f_\lambda)_n H_\lambda(\mathbf{r}_{\lambda i} - \mathbf{s}_n) + b_\lambda + \nu_{\lambda i}$$

pixel value — flux — PSF — background — noise

Noise model:

$$\sigma_{\lambda i}^2 = \underbrace{(\rho_{\lambda i} - b_\lambda)/g_\lambda}_{\text{[Poisson noise]}} + \underbrace{[(\rho_{\lambda i} - b_\lambda)(\sigma_{\rm ff})_\lambda]^2}_{\text{[Flat-fielding error]}} + \underbrace{(N_{\rm R})_\lambda^2}_{\text{[Read noise]}}$$

$$+ \underbrace{(\sigma_b)_\lambda^2}_{\text{[background noise]}} + \underbrace{[(f_{\rm ap})_\lambda \delta H_\lambda(\mathbf{r}_{\lambda i} - \mathbf{s}_n)]^2}_{\text{[PSF error]}}$$

Solution procedure

Construct parameter vector:

$$\mathbf{z} \equiv [\{\mathbf{s}_n, \{(f_\lambda)_n : \lambda = 1, \ldots N_\lambda\} : n = 1, \ldots N_\mathrm{B}\}]$$

[Position of *n*th blend component] [fluxes at the multiple bands]

Maximize:

$$\ln P(\rho|\mathbf{z}, N_\mathrm{B}) = -\frac{1}{2}\sum_\lambda \sum_i \frac{1}{\sigma^2_{\lambda i}}[\rho_{\lambda i} - b_\lambda - \sum_{n=1}^{N_\mathrm{B}} (f_\lambda)_n H_\lambda(\mathbf{r}_{\lambda i} - \mathbf{s}_n)]^2 + \text{const.}$$

Evaluate quality of fit:

$$\chi^2_\nu = \frac{1}{N_\mathrm{obs} - n_\mathrm{p}} \sum_\lambda \sum_i \frac{1}{\sigma^2_{\lambda i}}[\rho_{\lambda i} - b_\lambda - \sum_{n=1}^{N_\mathrm{B}} (\hat{f}_\lambda)_n H_\lambda(\mathbf{r}_{\lambda i} - \hat{\mathbf{s}}_n)]^2$$

Estimated fluxes and positions

Active deblending

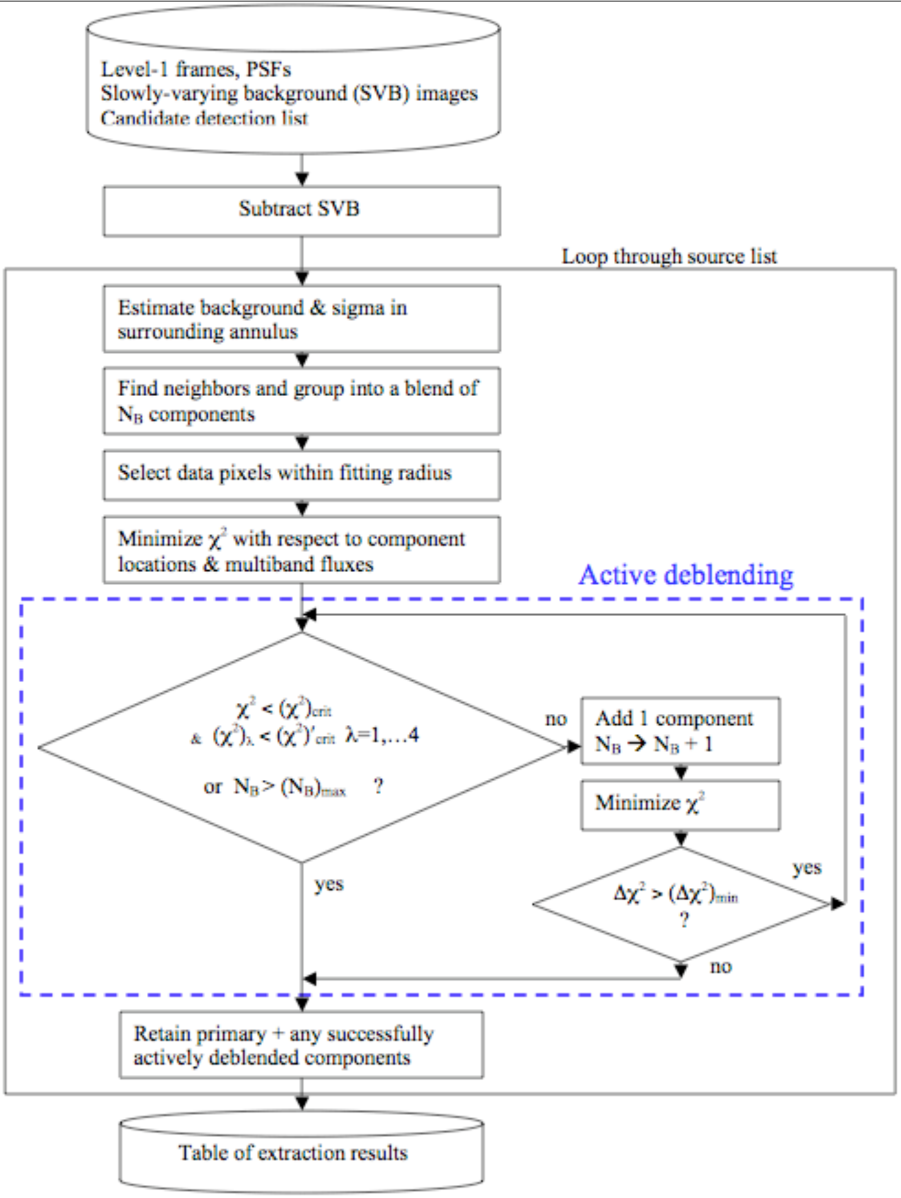
Steps involved in iterative procedure:

1. Chi squared test of current solution, with N_B components:
   If $c_n^2 > (c_n^2)_{crit}$ or $(c_n^2)_l > (c_n^2)'_{crit}$ for any l , then add new component.
2. Fix positions for N_B components & minimize c_n^2 over a grid of positions for new component, based on flux-only solution.
3. Use this as a starting model for full N_B+1 component solution.
4. Delta-chi test of relative likelihoods of the two models:
   If $[(c_n^2)_{NB} - (c_n^2)_{NB+1}] > (Dc_n^2)_{min}$ then new model is accepted and iteration continues until either this condition is violated or the maximum allowable number of components is exceeded, i.e. $N_B > (N_B)_{max}$

Key parameters:

- $(c_n^2)_{crit}$ => Completeness
- $(Dc_n^2)_{min}$ => Reliability

WPRO flow


Level-1 frames, PSFs
Slowly-varying background (SVB) images
Candidate detection list
Subtract SVB
Loop through source list
Estimate background & sigma in surrounding annulus
Find neighbors and group into a blend of N_B components
Select data pixels within fitting radius
Minimize χ^2 with respect to component locations & multiband fluxes
Active deblending
$\chi^2 < (\chi^2)_{crit}$ & $(\chi^2)_\lambda < (\chi^2)'_{crit}$ λ=1,…4 or $N_B > (N_B)_{max}$?
no
Add 1 component $N_B \rightarrow N_B + 1$
Minimize χ^2
$\Delta\chi^2 > (\Delta\chi^2)_{min}$?
yes
no
yes
Retain primary + any successfully actively deblended components
Table of extraction results

Aperture Photometry

The Aperture Photometry System (WAPP) performs multi-aperture photometry & additional source characterization.

Fixed aperture photometry serves several purposes, including:

(1) source flux estimation in support of profile-fitting photometry,
(2) construction of curve-of-growth data for aperture corrections,
(3) more accurate flux determination for very bright sources,
(4) serve as a 'truth' measurement to test the robustness of profile-fitting photometry, and
(5) accurate source flux determination for extended sources in which the PSF does not accurately model the light distribution.

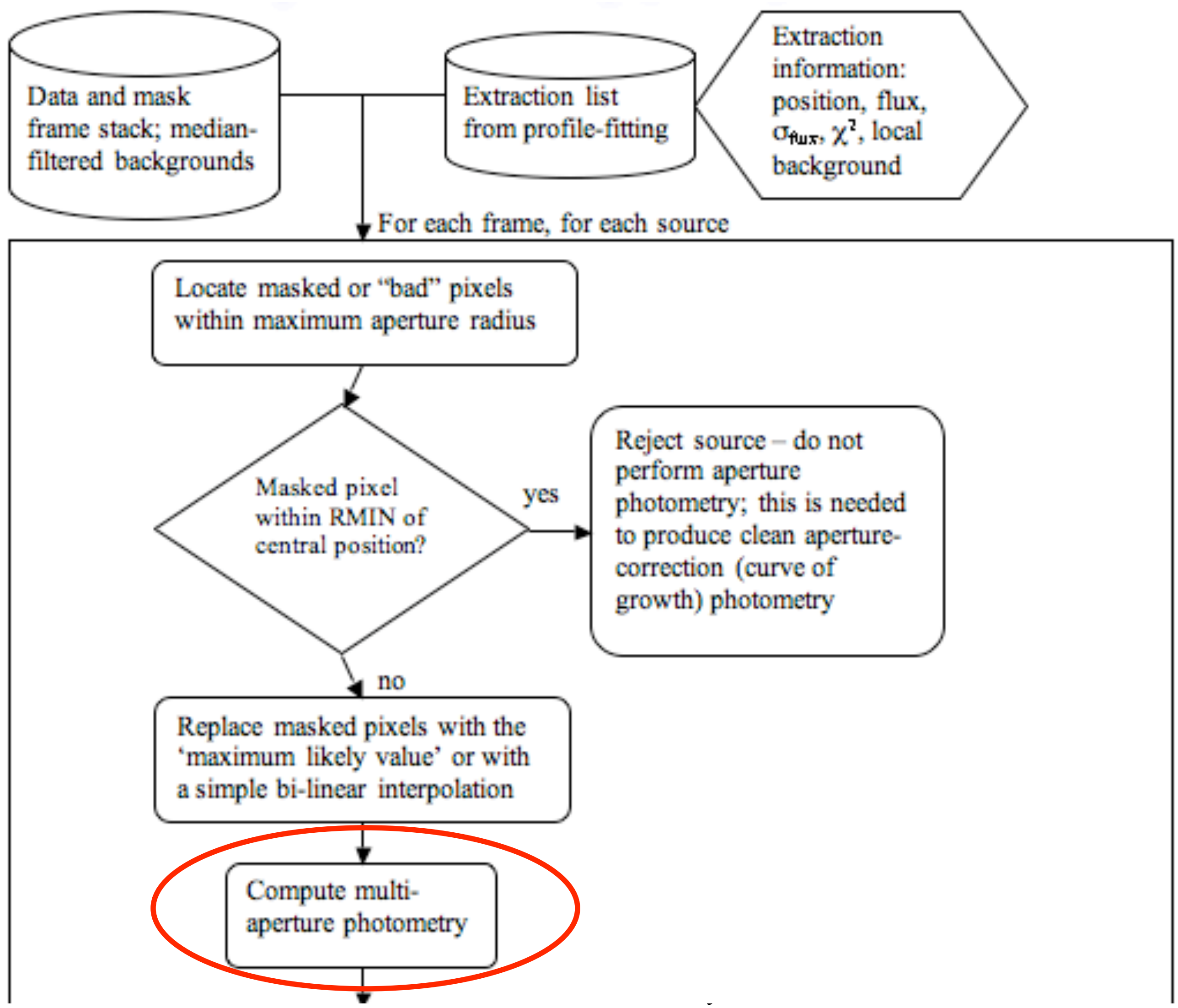
WAPP -- additional source characterization (as resources permit)

WAPP continued …

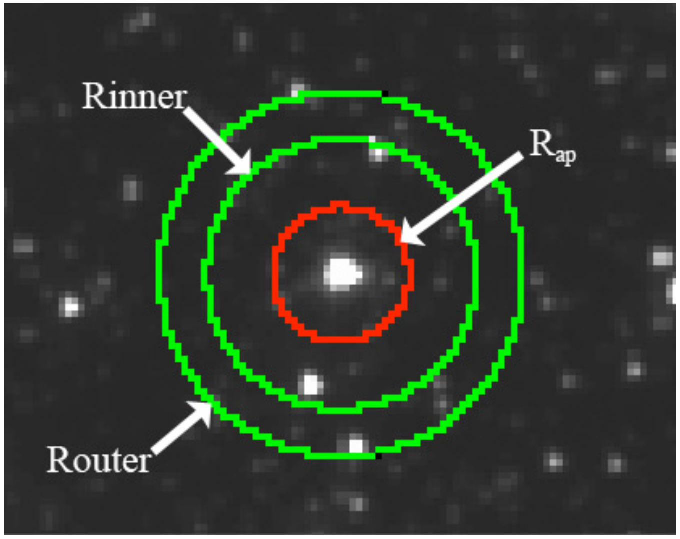
The WPRO extraction list is used as the input source list for WAPP. In this way every source extracted by WPRO using both passive and active deblending will have an aperture flux.

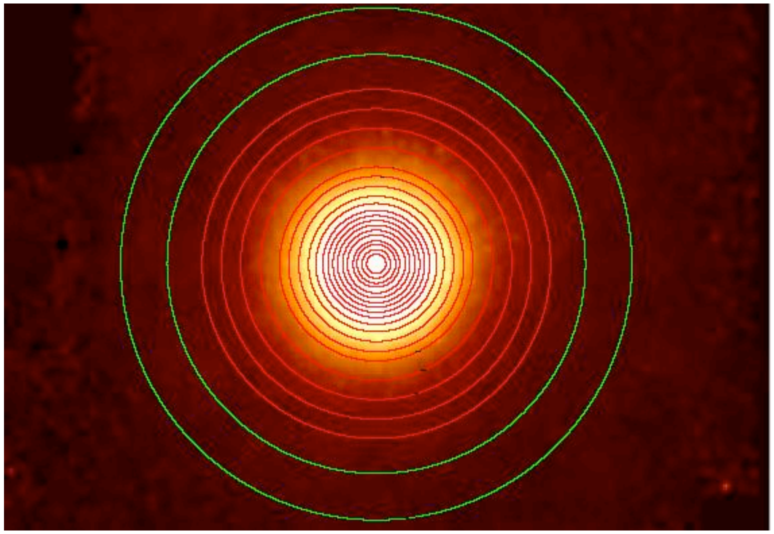
WAPP Flow

WPHOT



Aperture Photometry

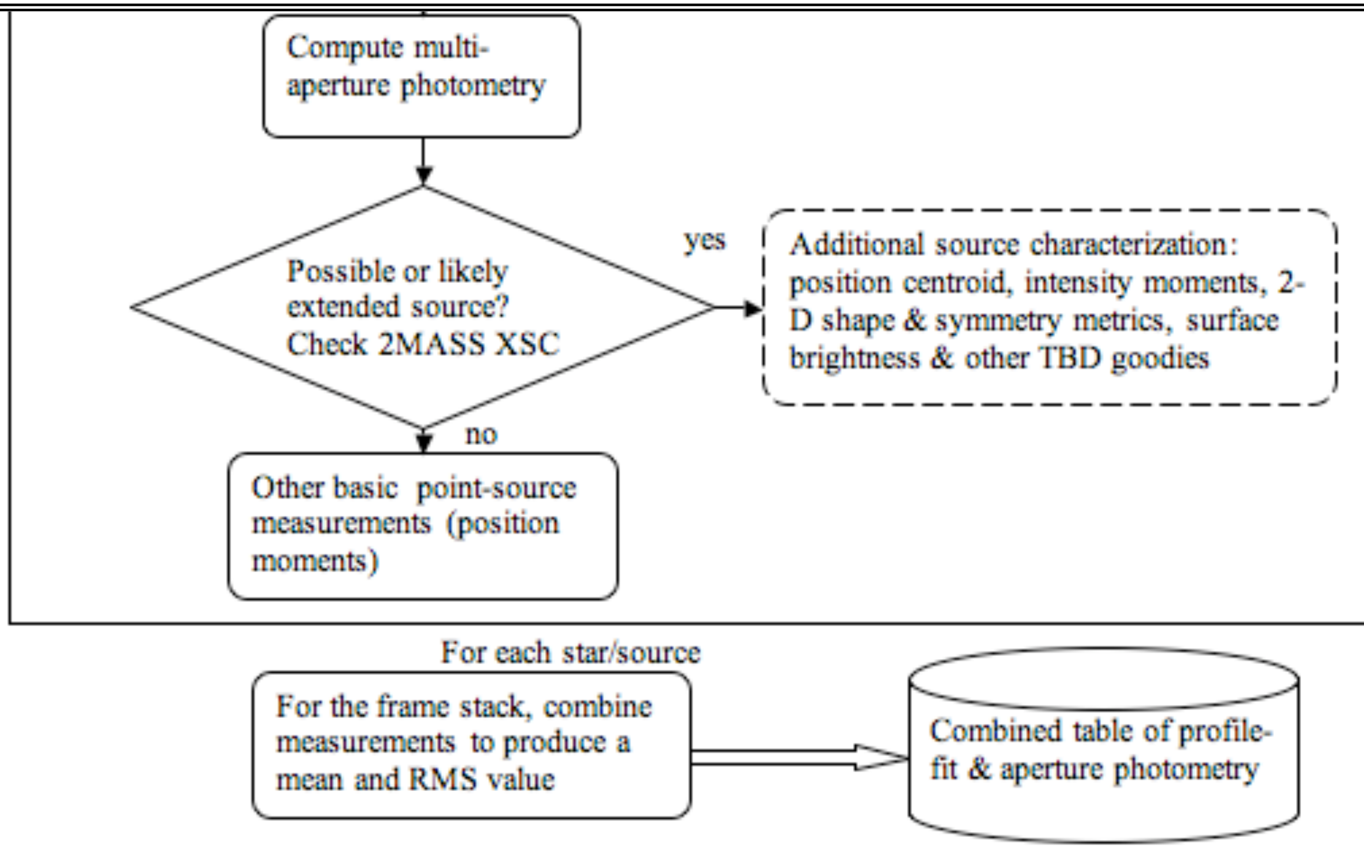




- *bad* pixels replaced with maximum likelihood values
- Local background annulus
- Nested apertures to capture curve-of-growth
- Stellar confusion?

- Nested apertures to capture extended source emission
- Integrated flux and source characterization limited by local background annulus size

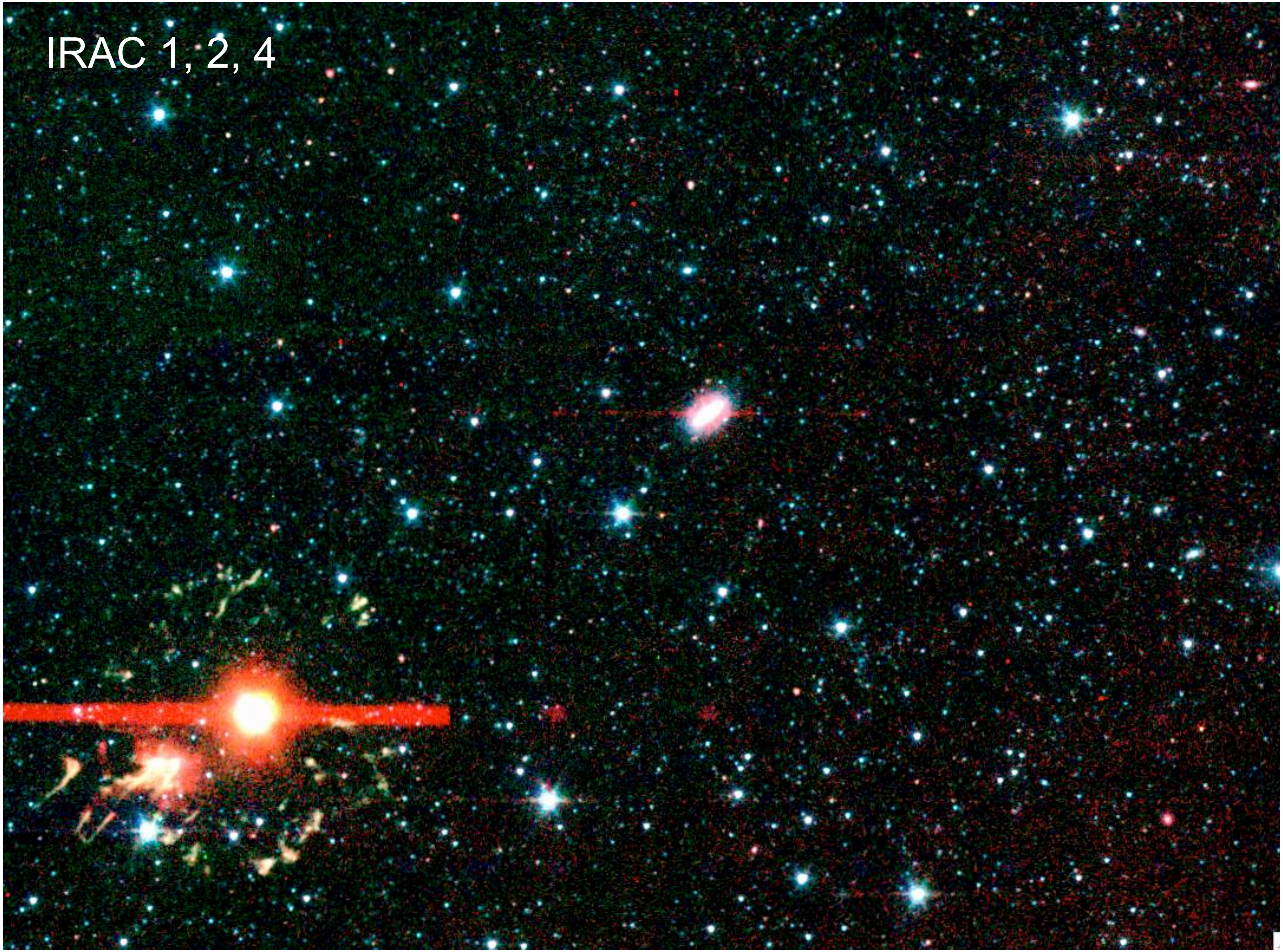
WAPP Flow


Compute multi-aperture photometry
Possible or likely extended source? Check 2MASS XSC
yes
Additional source characterization: position centroid, intensity moments, 2-D shape & symmetry metrics, surface brightness & other TBD goodies
no
Other basic point-source measurements (position moments)
For each star/source
For the frame stack, combine measurements to produce a mean and RMS value
Combined table of profile-fit & aperture photometry

Test (Plan) Description

Test Data Sets: WISE image simulations; Spitzer NEP/SEP mini-surveys, GLIMPSE, SWIRE; M67 (2MASS & IRAC)

- Integrity & robustness of the algorithms
- Reliability (χ^2 metric; active deblending; N out of M)
- Completeness in confused instances (WPRO)
- Memory management for deep coverages
- Speed management (active deblending thresholding)


IRAC 1, 2, 4

Test Description -- WAPP

WAPP Annulus/Aperture testing

- Local background statistics; pixel-value histogram statistics.
- Small apertures, to test the fractional-pixel algorithm.
- Large apertures, to test the integrity of the system.
- Full range in fluxes, from noise to bright-saturated stars.
- Compare frame with coadd measurements
- Requirements (e.g., bright stars)

Test Description -- WPRO

WPRO testing:

- Validity of noise model: plots of χ_ν^2 vs. magnitude
- Validity of quoted errors: repeatability tests based on multiple observations (e.g., Spitzer observations of NEP)
- Active deblending tests:
  -- Verify performance (completeness and reliability as a function of SNR, recovery of sources missed during detection step)
  -- Determine optimal values of deblending parameters
- Response to artifacts and extended sources:
  -- Saturated stars, diffraction spikes, latent images, etc.
  -- Effectiveness of χ_ν^2 as discriminator

Development Schedule

- Peer Review (March, 2008)
- v0 2/27/08 prototype (single frame, multi-band), data flow testing
  - Input frames, masks & detection lists
  - Local backgrounds (stats)
  - Aperture photometry
  - Preliminary output table
- v1 6/19/08 payload ground testing; prototype multi-frame
  - Input median-filtered background images
  - Profile-fitting (active and passive deblending, isoplanatic PSF)
  - Coadded aperture photometry (prototype multi-frame)
  - Other source Characterization
  - Full output table
- V2 2/28/09 Nonisoplanicity capability in WPRO, PSF generation software
- V3 8/4/09 Pre-launch version: Complete functionality, PSF set, optimized parameters
- V3.5 12/30/09 Post-launch tuneup of parameters/code
- V4 9/20/09 Version for final processing; PSFs derived from all available data

Things to Do/ Issues/Concerns

- PSF generation
- Focal Plane-dependent PSFs ??
- Focal Plane-dependent curve-of-growth measurements ?
- Parameter tuning
- Driving thresholds for active deblending
- Coadd measurements
- Upper limits
- Masked/bad-pixel recovery
- Extended sources (no plan to properly deal with)
- Very bright stars & saturated stars